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RESOLUTION OF CYGNUS A WITH A 52" BEAM

For some time, two-hump models have been used to interpret observations of the radio source Cygnus A. Thus Jennison and Das Gupta (1953) found that the source must have at least two distinct centres of emission and that the simplest distribution compatible with their interferometric observations at 125 Mc/s consisted of two components with an east-west separation of 88". This was later revised (Jennison and Das Gupta 1956) to 85" on the basis of further observations and most recently (Jennison and Latham 1959) to 82". Meanwhile, in further observations, also made at Jodrell Bank, Rowson (1959) showed the east-west separation to have a substantially greater value at 2800 Mc/s, and later observations by Lequeux (1962), Maltby and Moffett (1962), and Twiss, Carter and Little (1962) have tended to confirm a steadily increasing separation with increasing frequency, as summarized in Table 1.

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TABLE 1

Frequency	Angular Separation	Author
Mc/s		
127	82"	Jennison and Latham
958	89"±7"	Maltby and Moffet
1420	90"*	Lequeux
1427	90"†	Twiss, Carter and Little
2800	96"‡	Rowson
3292	98"±2"(r.m.s.)	This paper

*Value quoted as based on first minimum.

†Based on a spacing of 1150 wavelength for minimum visibility, as estimated from the published visibilities.

‡Based on a spacing of 1020 wavelengths and the quoted position angle 109°.

All these results were inferred from fringe visibilities observed at various antenna spacings on different occasions. In most cases the phase of the fringes was not taken into account. All the papers quoted express caution over their interpretations.

~~We are now able to report~~ direct resolution of Cygnus A at a frequency of 3292 Mc/s using the 52" inch fan beam of ~~the~~ a compound interferometer is reported. ~~at Stanford, and~~ on the basis of a firm determination of the actual peak-to-peak distance ~~we have reexamined~~ the existing data ~~we~~ examined and it was found ~~and find~~ that the reported dependence of separation on frequency is simply an appearance produced by the existence of a third-component whose spectrum differs from that of the main components.

The compound interferometer, which was designed by ~~W~~ Picken and Swarup, uses an array of sixteen equatorially mounted 10-foot paraboloids spaced at 25 foot intervals in an east-west line (Bracewell and Swarup 1961) plus two further 10-foot paraboloids in the same east-west line, one at the west ~~and~~ end and the other a further 325 feet to the west. All antennas are polarized with their electric vector east-west. The 16-element array produces a series of fan beams of half-power width $2'.3$, separated by 41'. When the output of the array is multiplied with that of the two extra elements, the half-power width of the individual beams is reduced to 52". The power response has the form $(16\pi x{-}1) \sin 16\pi x \cos 29\pi x \cos 13\pi x$, which exhibits alternative positive and negative lobes.

As the overall collecting area of the compound interferometer, including losses in transmission lines, is approximately equivalent to that of a 20-foot paraboloid, a number of scans must be summed to obtain a satisfactory record of Cygnus A. The passage of the source through approximately twelve beams near the meridian was observed each day, the receiver output was integrated for two-second periods, and was then recorded digitally. Fig. 1, the final record obtained from 12 days of observation, contains 148 scans of the source. In constructing this record a number of points near the two peaks of the source were interpolated using the method described by Bracewell (1962). The assymetry of the base-line in Fig. 1 is attributed to unidentified phasing errors of the order of 25°.

The origin of the ~~[illegible]~~ scale of angle is at the centroid of the source distribution, which had a right ascension of $19^{h}00^{m}00^{s}.0$ (1962.00) and is subject to an undetermined correction estimated to be less than 2^{s}.

The east-west spacing of the two peaks is 98" $\pm$ 2" r.m.s. error. The r.m.s. error was determined by replotting the double-peaked record several times with the addition of noise samples taken from the skirts of the record. Because virtually all systematic sources of error cancel out in the determination of spacing by this method of direct timing of two almost simultaneous transits, we have confidence in what appears to be unusual precision in an angular measurement by radio means.

The widths of the observed peaks are approximately 10 per cent greater than the theoretical width for a point source. The ratio of peak signal to r.m.s. noise is 11. In terms of a two-hump model we can say that the components cannot be wider than 50" , and that their flux densities in arbitrary units are each 1.0 ± 0.09 r.m.s. error. The agreement with Rowson's observations at the neighboring frequency of 3000 Mc/s is satisfactory.

The directly-measured peak separation thus confirms the interpretation of the 3000 Mc/s interferometry but raises the question whether the observations at other frequencies need reinterpreting, whether the data at lower frequencies are compatible with the existence of two sources spaced 98". A study of the data reported by Lequeux, which extend to east-west spacings of 6950 wavelengths at 1420 Mc/s, confirms that it is not possible to explain these observations on the basis of a simple two-hump model. We have therefore considered a model with more degrees of freedom, consisting of three Gaussian distributions whose heights, widths and locations are to be determined. Of the nine parameters only seven are assignable since the centroid and flux density of the source are not fixed by the data. The following model (Fig. 2) gives a good fit.

Component	Relative flux density	Width to half power	Abscissa
1	.375	15"	0
2	.375	23"	101"
3	.25	78"	43"

Corresponding to this model we can write a complex ~~fixxxx~~ fringe visibility $\mathcal{V}(s)$ given by

$$\mathcal{V}(s) = ve^{i\sigma} = 0.375e^{-0.22s^2} + 0.375e^{-0.55s^2}e^{-i2\pi 1.68s}$$
$$+ 0.25e^{-6s^2}e^{-i2\pi 0.72s}$$

This is shown as a locus on the complex plane of $\mathcal{V}(s)$ in Fig. 3, together with the corresponding graph of v versus s. The determination of the parameters of the model was carried out by straightforward manipulations on the complex visibility diagram, and led to a pair of equal components spaced approximately at the same spacing observed directly at 3292 Mc/s, plus a rather wide central component accounting for 0.25 of the total flux density.

We are now in a position to understand how this third component gave rise to the conclusion that the spacing depended on frequency. The first minimum in Fig. 3 occurs when the vectors representing the contribution of the main components are approximately in opposition. If there were only two sources, one could assume that the two vectors were precisely in opposition and deduce the source spacing. This in fact is what was done by all the authors referred to insofar as they were obliged to restrict attention to antenna spacings not extending much beyond 1200 wavelengths. However, when the two main vectors are in opposition, the vector associated with the central source is approximately in quadrature, and so the minimum shifts to a larger antenna spacing where the quadrature vector is approximately canceled by the resultant of the two main vectors. Maxima and minima of higher order fall more closely where conjunctions and oppositions occur, because the relative effect of the wide central source diminishes at the greater spacings. While the Lequeux data do not define the locations of the higher order maxima and nimima with great sharpness, the effect is nevertheless discernible, and was reported as an increase from 90" to 108" in the apparent angular spacing of the components according as the position of the minima from which it was deduced ranged from 1000 to 7000 wavelengths. (The entries in Table 1, except for the last, give the value deduced from the first minimum in all cases.)

Since the first minimum at 127 Mc/s is pulled even further from the 3000 Mc/s position than is the case at 1420 Mc/s, the third component must be even stronger. In this case, the maximum at about 2000 wavelengths would be reduced relative to the maximum at zero spacing, and this in fact is precisely what is observed.

By simply increasing the strength of the third component from 0.25 to 0.46 without changing its location or width we can account for both the location of the first minimum and the height of the first maximum in the visibility curve.

The calculated visibility curve for 127 Mc/s is shown in Fig. 3, together with the observational data.

We conclude that, on present data, Cygnus A consists of two components spaced approximately 98" apart at all frequencies, together with an extended central component 78" wide to half power amounting to 0.38 of the total flux density at 127 Mc/s and 0.25 at 1420 Mc/s. The central component has a markedly different spectrum from that of the outer components. If the flux density of Cygnus A, as a whole, is taken to vary with frequency as $f^{-0.8}$ then the central component has the much steeper spectrum $f^{-1.0}$. If this spectral law persists to 3000 Mc/s, then the central component should also be detected at this frequency in due course.

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10 by G. Swarup,
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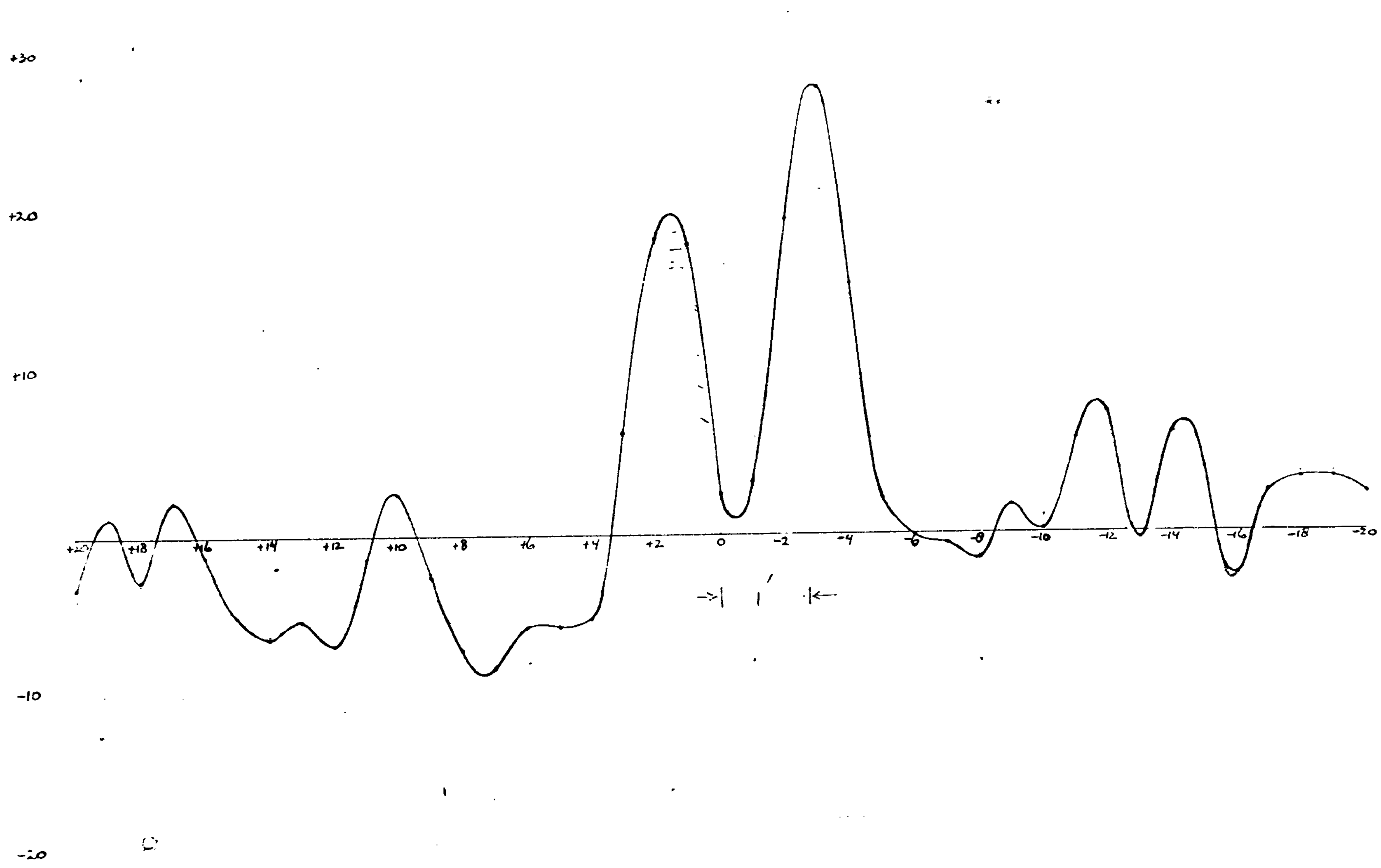
FIGURE CAPTIONS

Fig. 1 - Composite record of Cygnus A based on 148 drift scans with the 52" beam.

Fig. 2 - Model of Cygnus A involving a wide central component.

Fig. 3 - Calculated visibility curve and observational data taken at 1420 Mc/s.



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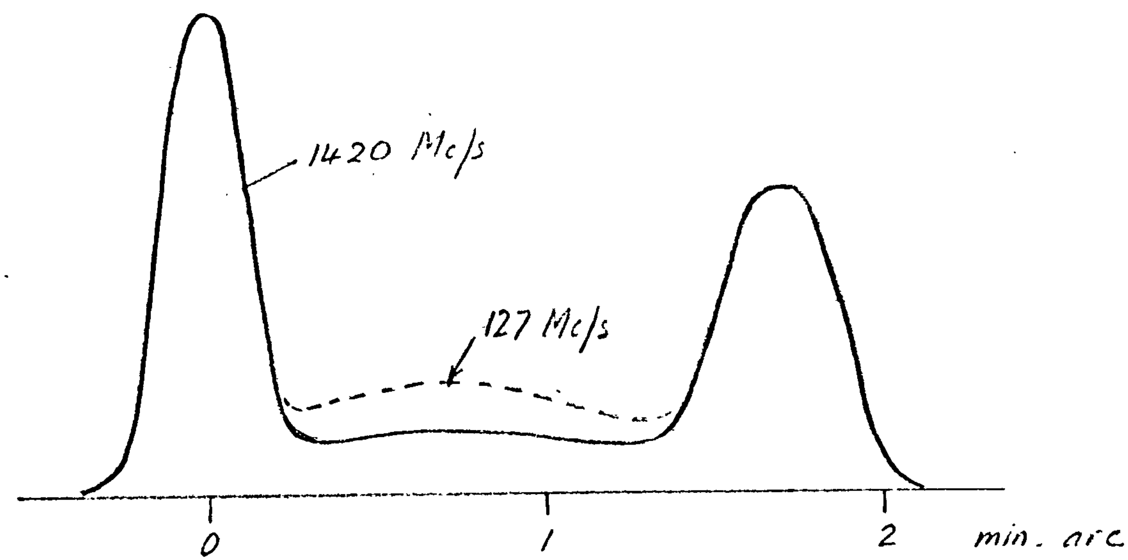
1420 Mc/s
127 Mc/s
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2
min. arc

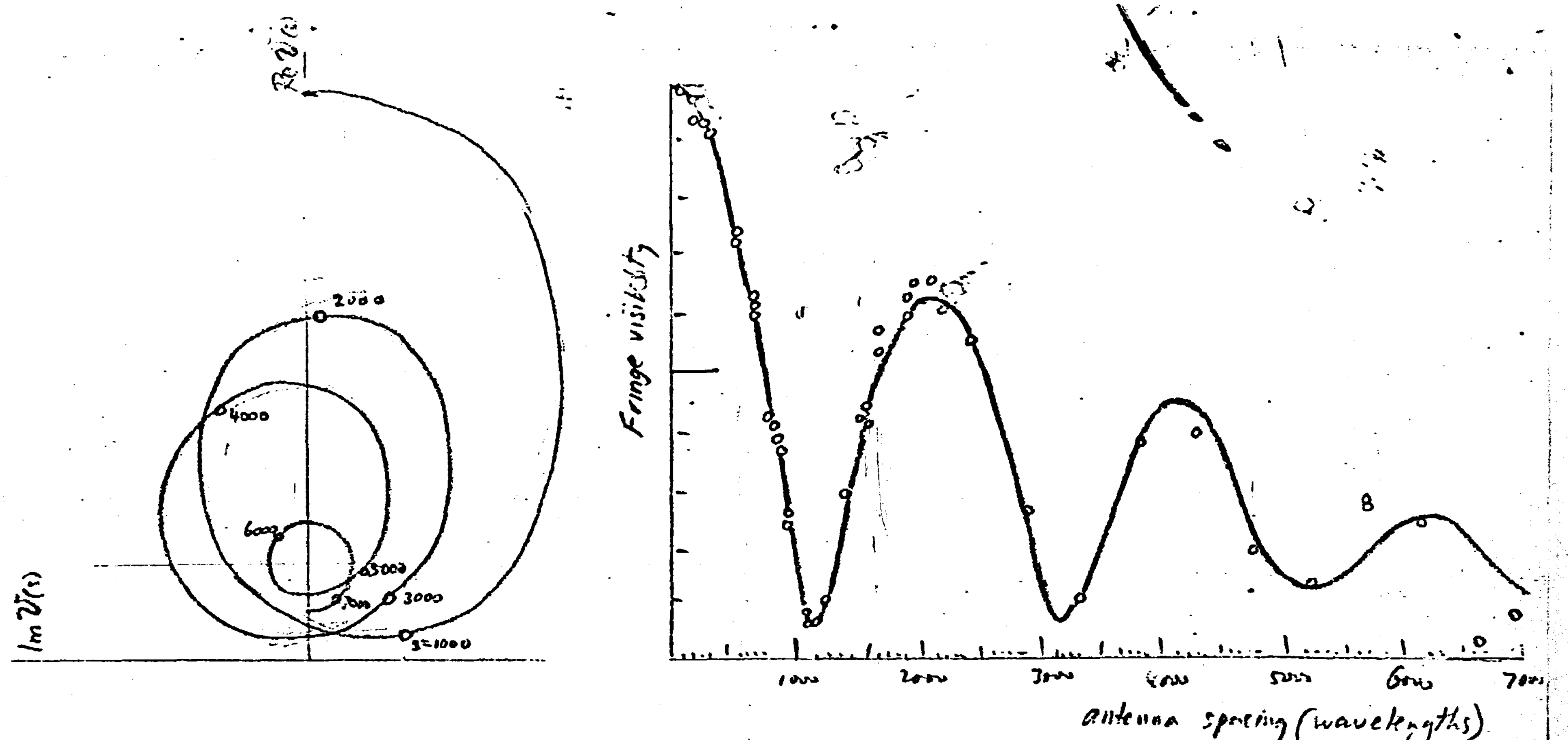

Fig 3

Sequence data
Include .127 Mc/s curve?